

PHOTOMASK

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Defect Reduction of Patterned Media Templates and Disks

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Abstract

Imprint lithography has been shown to be an effective technique for the replication of nano-scale features.

Acceptance of imprint lithography for manufacturing will require a demonstration of defect levels commensurate with cost-effective device production. This work summarizes the results of defect inspections of hard disks patterned using Jet and Flash Imprint Lithography (J-FIL™). Inspections were performed with optical based automated inspection tools.

For the hard drive market, it is important to understand the defectivity of both the template and the imprinted disk.

This work presents a methodology for automated pattern inspection and defect classification for imprint-patterned media. Candela CS20 and 6120 tools from KLA-Tencor map the optical properties of the disk surface, producing high-resolution grayscale images of surface reflectivity and scattered light. Defects that have been identified in this manner are further characterized according to the morphology. The imprint process was tested after optimizing both the disk cleaning and adhesion layers processes that precede imprinting. An extended imprint run was performed and both the defect types and trends are reported.

1. Introduction

Imprint lithography has been shown to be an effective technique for replication of nano-scale features. When the imprint material is a photo curable liquid, it is possible to perform the patterning process at low temperature and ambient pressure, which enables accurate overlay and reduces process defectivity. The resolution of the imprint approach is strictly dependent on the ability to create a 1X master mask or template, and improvements in resolution can be achieved without

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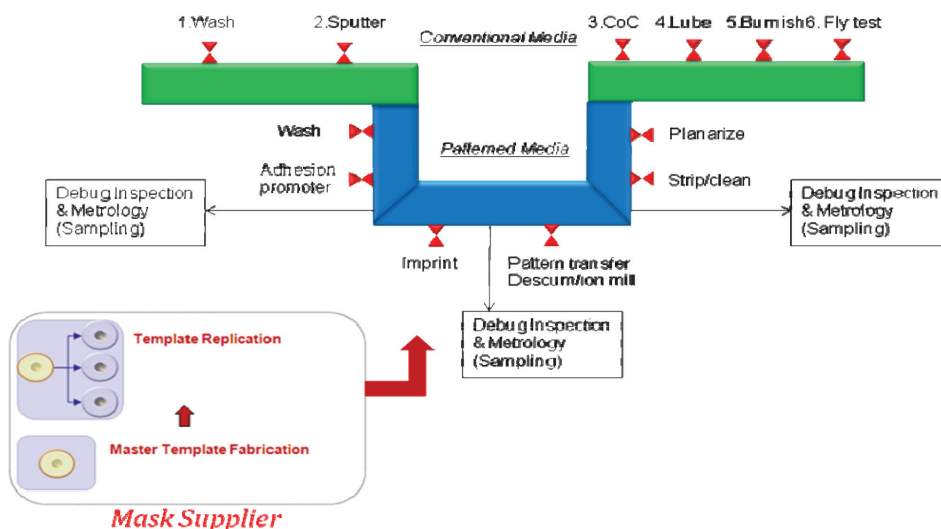


Figure 1. Patterned media manufacturing flow.

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SPIE

EDITORIAL

EMLC the 2nd time in Grenoble

By Dr. Uwe Behringer, UBC Microelectronics

As was the case two years ago, the January 2010 EMLC edition in Grenoble, France was a success, with more than 150 scientists from 10 countries, 41 companies, institutes and universities. We find it interesting to come back to this info mid-year to compare it to the perspective of the upcoming BACUS when the trends are hoped for to be more positive. Firstly, the plenary speakers, Gerard Matheron (STM Crolles, Grenoble, France) and Rolf Seltmann (Globalfoundries, Dresden, Germany) talked about their view regarding market and technologies. Both presentations are on the website: (www.emlc2010.com). Dr. Greg Hughes (SEMATECH) presented the economic status of the photomask industry. The weakness of the market in 2009, especially for manufacture equipment (50% drop, Fig.1) is compared to the market situation for photo masks over the last 23 years (Fig.2, a 19% decrease, 2009 compare to 2008).

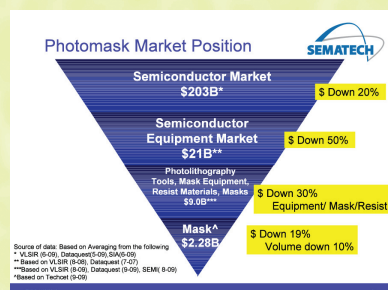


Fig. 1. Photomask Market position in 2009.

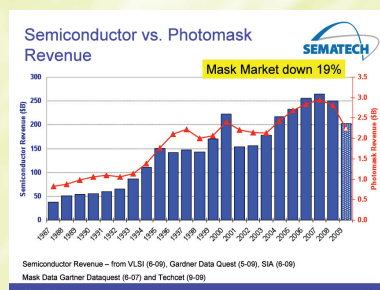


Fig. 2. 2009: Photo mask market trends.

In Lithography and Metrology sessions, Dr. Kautschik (Intel, Santa Clara) explained that Intel will use the 1,35 NA ArF Immersions Lithography for 32nm structures and for 22nm structures with liquids with a higher density than water and the EUV for the 16nm node. Dr. Roeth (KLA-Tencor, Weilburg, Germany) talked about the "IPRO Next Generation Tool" for the "Double Patterning Lithography, DPL". The new metrology tools have to measure 2 to 3 time better. As reported in the Resist, Repair & Cleaning session, Carl Zeiss SMS has developed a new method using an electron beam to induce etching or deposition processes. Dr. Markus Waiblinger (Carl Zeiss Jena, "Best Paper Award of EMLC2010") showed how the MeRiT 32 e-beam repairs clear and opaque defects (Fig. 3). Depending on the kind of the precursor molecules, the focused e-beam immobilize them leading to deposition or volatilize them leading to etching.



Fig 3. E-beam induced photomask repair. Left deposition, right etching.

about 9m² compare to 0.07m² of a 300 mm wafer.

The EMLC2011 is scheduled on January 19th to 20th 2011 at the Hilton Hotel Dresden. Please see our website: www.emlc2011.com.

Application: Tor Sandstrom from Micronics, Sweden talked about the mask fabrication and application for the production of Flat Panel Displays. While not a normal subject for a conference for mask and lithography techniques, the different problems in the fabrication of Flat Panel Displays highlight the manufacturing problems at a different scale. The mask size in the semiconductor technology is 6" = 150mm and an area of 0.0225 m². Masks for G10 generation of Flat Panel Displays have an area of 3 m²! The mother glass for the screens have the area of 2.9 x 3.1 m² which is

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Continued from cover.

Post Clean Particle Counts

SSEC Clean			Ivenpro Clean		
Disk	Particles (>300nm)	Particles (<300nm)	Disk	Particles (>300nm)	Particles (<300nm)
02B	0	51	01B	0	19
03B	0	32	01A	0	19
06B	0	31	07B	0	15
09B	1	39	07A	0	15
12B	0	14	13B	0	14
15B	0	38	13A	0	8
18B	0	36	19B	0	17
21B	1	26	19A	0	21
23B	1	52	25B	0	17
24B	0	24	25A	1	6
Avg	0.3	34.3	Avg	0.10	15.10
Stdev	0.5	11.7			

Figure 2. Representative post cleaning results for the SSEC and Cleanline disk cleaners. PRE is improved by about a factor of two with the new clean tool.

new optical systems or photo resist materials. In this sense, imprint lithography is a multi-generational technique that is being used to facilitate device and process prototyping at several upcoming lithography nodes.

Acceptance of imprint lithography for manufacturing will require a demonstration of defect levels commensurate with cost-effective device production. This work summarizes the results of defect inspections of hard disks patterned using Jet and Flash Imprint Lithography (J-FIL™).¹⁻⁷

It is anticipated that bit patterned media (BPM) will be required for very high density hard drives (~1Tb/in²).⁸⁻¹⁰ It is possible, however, that an interim solution such as discrete track media will be adopted for earlier insertion. Discrete track media consists (DTM) of an array of concentric lines (or tracks), with half pitches on the order of 50nm and below. The formation of the tracks is challenging because of the line densities required over substantial distances.

For the hard drive market, it is important to understand the defectivity of both the template and the imprinted disk.

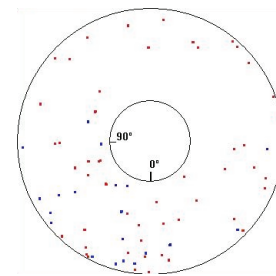
This work presents a methodology for automated pattern inspection and defect classification for imprint-patterned media. Candela CS20 and 6120 tools from KLA-Tencor map the optical properties of the disk surface, producing high-resolution grayscale images of surface reflectivity and scattered light. We have developed software that analyzes these images and identifies defect pixels distinctly from the pixels that correspond to data storage structures or servo patterns.

Defects that have been identified in this manner are further characterized according to the morphology of the defect pixels as well as the defect location on the substrate. The imprint process was tested after optimizing both the disk cleaning and adhesion layers processes that precede imprinting. An extended imprint run was performed and both the defect types and trends are reported.

2. Disk preparation

To enable patterned media for Hard Disk Drive (HDD) applications, it is expected that several process steps will be integrated in to the current media fabrication process flow.¹¹ Figure 1 shows the added patterned media process module. Compared to conventional blank media, the manufacturing flow adds several more key steps. The

Post Sputter Defect Map (Disk 19B)



Post Clean Defect Map (Disk 19A)

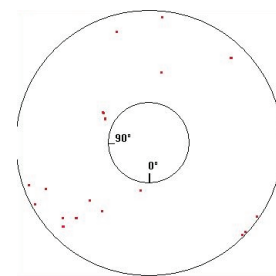


Figure 3. Candela particle maps: after metallization and after the new clean process.

process steps which are important for successful imprinting include: 1) post-sputter disk wash to

remove particles and contamination introduced during sputter process (such as large metal clusters), 2) a vapor deposited adhesion layer for better imprint resist bonding to the disk top surface, and 3) Jet and Flash Imprint Lithography to create the nano-patterns. Other manufacturing steps include a post imprint descum and etch, resist strip, and planarization. The adhesion promoter and imprint steps require new processes to be integrated, which have not previously been incorporated by hard disk manufacturers. The development of both the disk cleaning and adhesion layer is reviewed in the following two sections.

a. Disk cleaning

Imprint lithography requires template and substrate conformal printing to achieve high feature fidelity and reproducible uniform residual layer thickness (RLT) across the entire imprint area. It is conceivable that if there is a particle on the disk surface during imprinting process, it may lead to a local discontinuity between the template and substrate, resulting in RLT non-uniformity. Large particles can also cause imprint feature distortion. Hard particles, including metals and SiO₂ have, on occasion, caused permanent damage to the template. Therefore, it is critical to clean the disk after metal sputtering and prior to imprinting to enable a high yield process.

The second benefit of implementing a disk wash process is the enhancement of the adhesion force between the resist and the substrate, which is achieved by removing any surface contamination on the substrate and therefore increasing the adhesion layer bonding density on the disk top surface layer (See Section 2b).

Different from the conventional disk wash process, which typically uses DI water with detergents for bare substrates, SC-1 cleaning has been applied to clean the disk. SC-1 consists of the mixture of NH₄OH, H₂O₂ and DI water. A modified SSEC single wafer cleaner was initially used to clean the disks. Typical steps include double-sided brushing with SC-1 chemicals, a DI water rinse in the brushing module, a single-sided brush high velocity

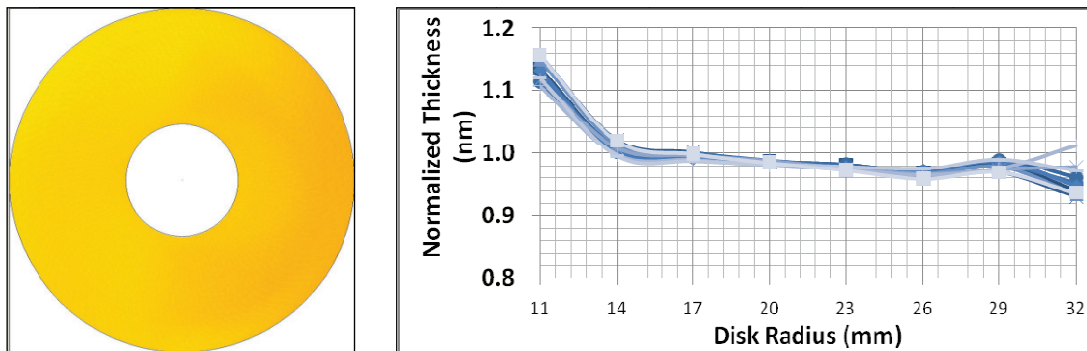


Figure 4. VALMat uniformity measured by using Candela (left) and normalized VALMat thickness on Ta coated disks.

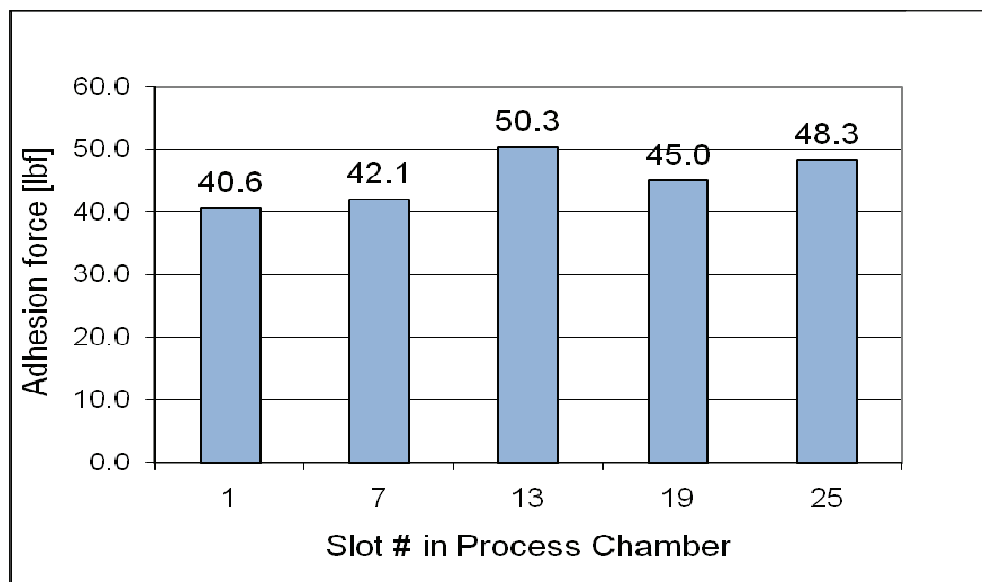


Figure 5. Adhesion shear test results on Ta coated disks.

SC-1 spray, a DI water rinse and a spin dry with nitrogen. Particle detection was performed with a Candela 6120 inspection system.

An optimized clean process yielded an average particle count of 0.3 and 34.3 per disk surface for particles >300nm and <300nm, respectively.¹² Particle sizes were calibrated using polystyrene latex (PSL) spheres. It was also observed that disk cleaning of the back side of the disks suffered relative to the front side. In order to reduce particle counts and extend the life of a template, a new disk clean tool was installed.

In order to improve cleaning efficiency, a Cleanline disk cleaner provided by Ivenpro was installed and characterized. The basic process includes a DI pre soak, followed by an SC1 brush clean and an SC1 post soak with sonication. A cascade rinse and quick dump rinse are then employed, followed by a hot N2 dry. Figure 2 compares the post cleaning results from both tools. Both large and small particle counts are reduced with the new cleaner. Figure 3 displays Candela images of both the incoming metalized disk and the same disk after the new clean process. Particle removal efficiency for the Cleanline system for large (>300nm) and small (<300nm) particles is 0.97 and 0.42, respectively.

b. Disk adhesion layer coating

Good adhesion between the adhesion layer and imprint resist is critical for imprint longevity and high yield. To enhance adhesion, an adhesion promoter coating step has been added into the process flow. Since low cost of ownership in the fabrication of patterned disk media (PM) is an essential requirement for manufacturing, an adhesion promoter, VALMat, was specifically designed to have low molecular weight and high vapor pressure at room temperature. As a result, the material can be applied to a disk surface by using vapor deposition. This is a preferred method for coating, since vapor deposition processes can achieve excellent uniformity across the disk surface. In addition, the process allows both batch processing and doubled sided coating. Intevac provided the vapor deposition system. Figure 4 shows the VALMat uniformity measured by using a Candela inspection system (left) and normalized VALMat thickness across the disk surface on Ta coated disks (right). The process was then tested across a 25-disk cassette of disks. All the disks had an approximate thickness of 1nm thick, with a coating uniformity of ± 0.1 nm. The adhesion layer film growth is self-limiting so that only a monolayer is deposited.

VALMat bonds well with many substrates used in patterned

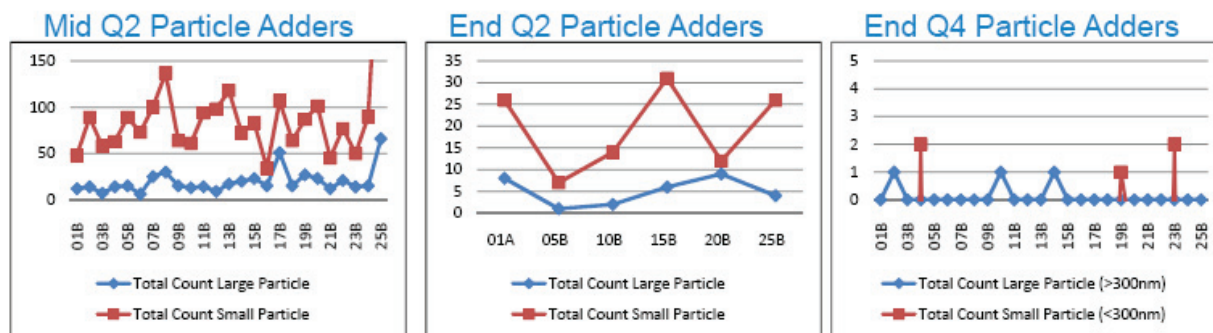


Figure 6. Particle adders per disk over the course of approximately six months. Currently, the VALMat process adds less than 0.2 adders per disk surface.

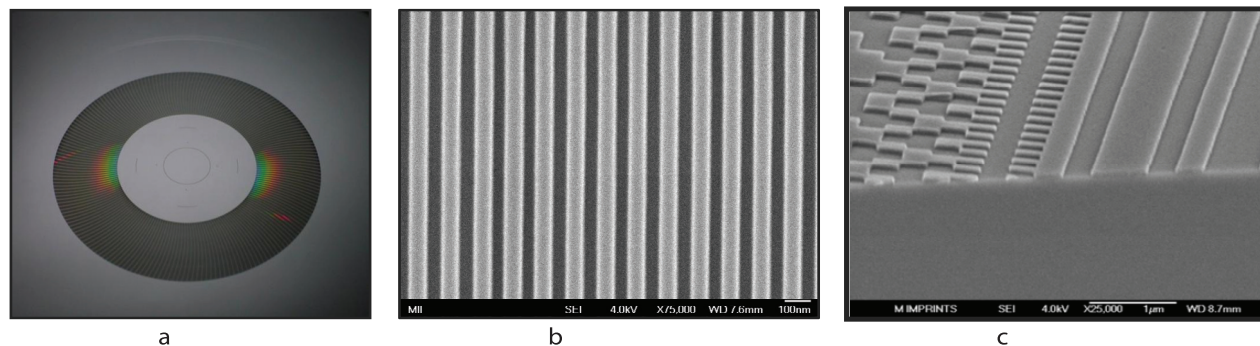


Figure 7. a) Optical image of the replica template. b) SEM of the discrete tracks. c) SEM of the generic servo patterns.

media applications such as Si, SiN_x, Ta, and SiO₂ and imprint resist. Figure 5 shows the typical adhesion forces between VALMat and tantalum. One cassette of disks was coated in the LithoPrime vapor deposition tool. Five disks were selected for the adhesion test. The adhesion force test is a shear test and measured by using an Instron 5542. The adhesion test exhibits an average adhesion force of 45.26 lbf with a standard deviation of 4.07 lbf. Compared to DUV30J (a commercially available anti-reflective coating), the VALMat demonstrates an adhesion force improvement on tantalum coated disks by a factor of 10.

As discussed in Section 2a, surface cleanliness is a crucial factor for successful imprinting. Higher density hard drives require reduction in pattern dimensions, accompanied by commensurate decreased in both template etch depth and residual layer thickness. This subjects the imprinting process to even greater control over particulates and surface contamination. Particles on the disk surface can be controlled by using post sputtering wash. Contamination, especially, airborne organic contamination, needs to be carefully controlled using additional processing. In-situ organic surface contamination removal prior to VALMat coating is essential, since the VALMat coating depends on a clean pristine surface. In this work, an ozone process was used to remove organic contamination. LithoPrime has the capability for insitu ozone cleaning. The process is as follows: after disks are loaded into the process chamber, the chamber is pumped down to a high vacuum. Then, high concentration ozone is introduced the chamber to remove the organic contamination. After the ozone surface treatment, ozone is evacuated and followed by the VALMat vapor deposition process. Up to 25% increase in adhesion force on Ta coated disk has been observed as a resulting of inserting the ozone step.

The cleaning effectiveness depends on the ozone concentration level, ozone process pressure and process time. Contact angle (CA) measurement provides useful information as to the effectiveness of the ozone cleaning process and the VALMat film coverage. Previous work discussed the benefits of the ozone process.¹² Droplet contact angle on an SC-1 cleaned Ta surface was measured as a function of ozone process time. A decrease in contact angle with increase in ozone process time was clearly observed. With a 1 minute ozone process, the CA was quickly reduced to ~30 degrees. Further increases in process time to 30 min achieved a contact angle close to zero.

It should also be noted that the entire process adds almost no defects to the disk surface. A typical cassette of disks yielded 0.1 and 0.2 adder per disk surface for >300nm particle and <300nm particles, respectively. Figure 6 shows the improvement of the process over the course of approximately six months.

3. Patterned Media Results

a. Template and disk inspection preparation

The replica template used for inspection work was fabricated from a master template supplied by Hoya with 120 nm pitch media and an accompanying set of generic servo patterns. The patterns started at an inner radius of 16.5 mm and continued out to a radius of 31.5 mm. Replication of the master was done using an Imprint 100TR system. Pattern transfer of the template was done in an RIE etcher from Trion. The replica template, discrete tracks and servo patterns are shown in Figure 7.

Two-sided imprinting of disk substrates was performed with an Imprint HD2200 – a fully automated UV nanoimprint lithography

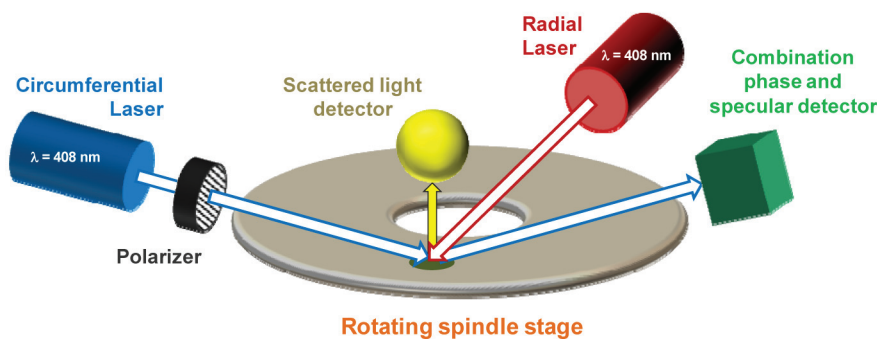


Figure 8. Schematic of optical components in a Candela® inspection tool.

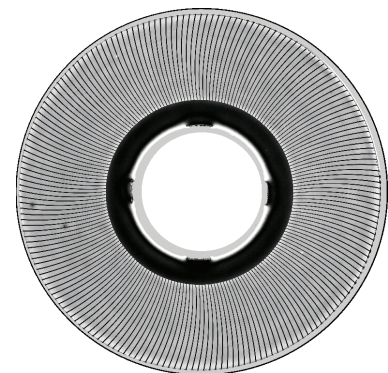


Figure 9. Candela image of a template.

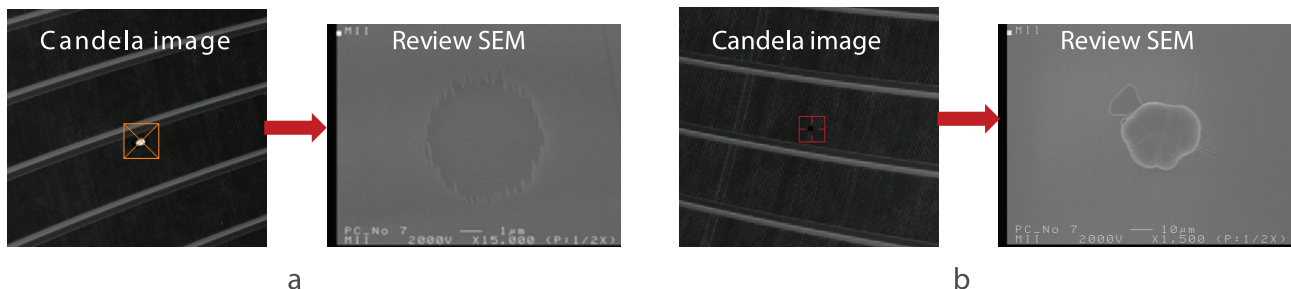


Figure 10. Defects detected with the Candela on a replica template. a) Missing patterns, b) particle on top of the pattern.

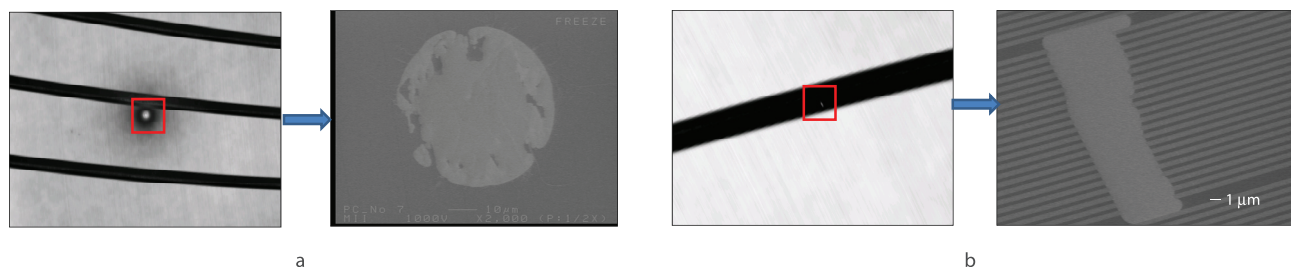


Figure 11. Imprint defects: a) Particle induced defect. b) Non-fill defect.

tool that has been specifically designed for patterned media applications.¹³ The Imprio HD2200 provides the high patterning fidelity that is characteristic of UV-nanoimprint lithography, with automated double-sided disk patterning capability and throughput of 180 disks per hour. Patterned media applications typically require a modest level of alignment (tens of microns) to ensure that the patterns are concentric to the spindle axis of the disk drive unit; the Imprio HD2200 provides alignment of the template pattern to the disk substrate within 10 μm . The next generation system, the NuTera HD7000 was delivered in the first quarter of 2010. Throughput has been increased to over 300 disks/hour, double sided. Future work will report on the performance of this new system.

b. Inspection characterization

Inspection on both templates and disks were performed using Candela systems from KLA-Tencor. Candela tools scan the substrate surface under the stationary inspection spot of the X-Beam™

Optical Surface Analyzer. Two high stability laser sources (with adjustable polarization) are directed to this location in radial and circumferential orientations, and multiple detectors are employed to measure the scattered light as well as the intensity and phase of the specular reflection. This flexible configuration permits both bright field and dark field inspection modes as well as quantitative thin film ellipsometry measurements. Originally used for inspection of ultra-thin lubrication layers on unpatterned disk surfaces, these tools are also useful for inspection of the next generation of patterned media. A schematic of the Candela is shown in Figure 8. A typical scan image is shown in Figure 9.

Implementation of PM in production requires pattern inspection at levels of resolution and throughput that are sufficient to obtain meaningful statistics on process yield; this metrology facilitates the feedback loop that is essential for process optimization and control. Fortunately, a disk drive is more tolerant of defects than a typical semiconductor device. For example, a low level of small,

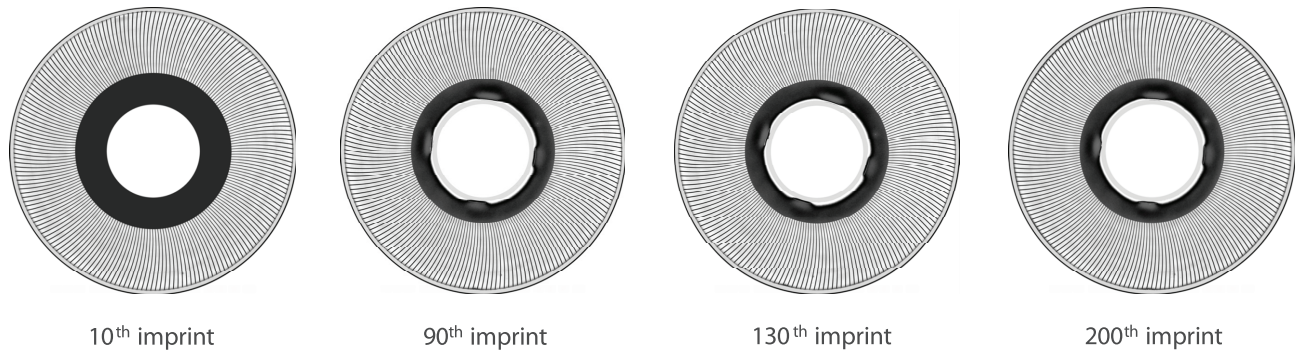


Figure 12. Candela images of four disks over a 200 disk run.

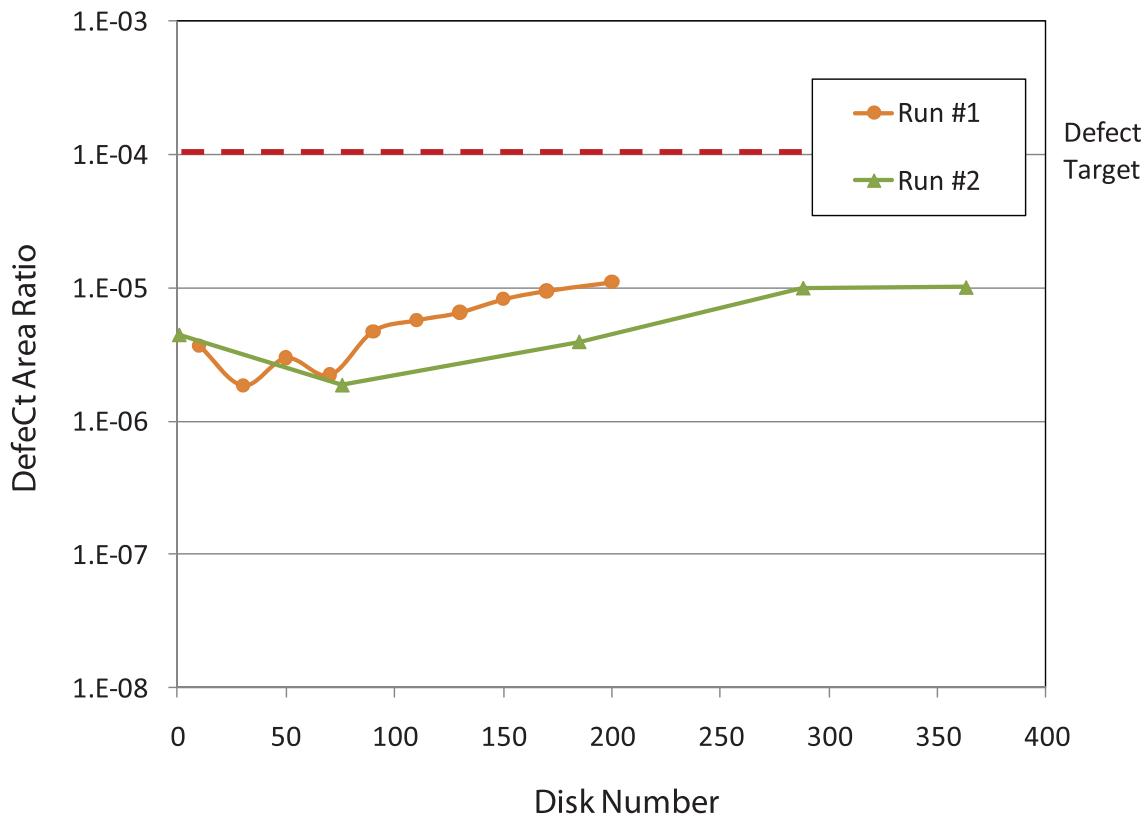


Figure 13. Defect area ratio as a function of imprint number for two runs. An improved cleaning process is effective in reducing defectivity. The total defectivity is well under the target of $1e-4$.

isolated defects can reduce the area that is available for data storage, but the overall performance of the disk drive is not affected. This level of defect tolerance can be specified simply in terms of the fraction of the disk surface that is unusable for recording data. However, defects within the servo patterns are more problematic because these defects can impair the function of the drive head. This issue is mitigated through use of fault-tolerant servo pattern designs, but increased fault tolerance requires a larger portion of the disk surface to be devoted to servo marks (at the expense of data storage). The tolerance specifications for lithography defects are thereby tied to a number of other process and design decisions.

The details of the lithography defect specifications (proprietary to each media supplier) will determine the appropriate defect inspection strategy. While details of the defect inspection strategies vary, it is clear that pattern inspection will occur at multiple points during the PM lithography process, beginning with the qualification of templates. As is the case for replica masks for semiconductors, replica templates and patterned disks require short inspection times due to the much larger volume of substrates.

Candela inspection systems were used for all inspections. Although the minimum pixel size of the optical system (~1 micron) is much larger than the lithographic patterns, the stability of the

optical systems and the availability of multiple inspection channels enable detection of sub-200nm pattern defects. To investigate the sensitivity of the Candela tools for detection of small pattern defects, a test template was prepared with arrays of programmed defects embedded within a DTM layout having a track pitch of 120nm. The programmed defect array consisted of rectangles ranging from 0.12 μm to 7.68 μm , with varying aspect ratio in both down-track and cross-track directions. Both the scatter and specular channels were tested. The scatter channel is found to be more sensitive for capture of small defects, with nearly complete capture of programmed defects having a footprint area of at least 0.1 μm^2 . The specular channel is somewhat less sensitive for detection of the smallest programmed defects, with an apparent threshold area of $\sim 0.5 \mu\text{m}^2$. However, the specular channel image reveals pattern details that are not seen with the scatter image. For example, two non-programmed pattern errors were evident as horizontal lines; these errors originated as electron-beam stitching errors.

The sensitivity for defect detection is highest when the lithographic pattern provides a uniform background for inspection; such is the case for the grating-like features that comprise the recording tracks for DTM, or the pillar arrays for BPM. Servo patterns generally have very different optical properties than the recording regions, which obscure the detection of defects in these regions. Further details on Candela characterization can be founded in references 11 and 12.

c. Defect analysis

Examples of defects seen on the template are shown in Figure 10. The most common defect type is missing patterns, as shown in Figure 10a. This type of defect shows up as a bright spot on a dark background. Particle type defects tend to be darker than the media background as shown in Figure 10b.

Figure 11 displays the most common defects during the imprint process: particles and non-fill defects. Particle defects are the dominant defect and result primarily from insufficient cleaning of the disk. Non-fill defects are small in number relative to particle defects, and occur primarily from imperfections in the drop generation pattern. Small refinements to the software will further reduce this defect type.

Two runs were performed: the first run consisted of 200 disks and used the SSEC clean process. Candela images of four of the disks from the second run are shown in Figure 11. Shown are the images from disks 10, 90, 130 and 200. The second run took advantage of the improved Cleanline clean process. A total of 375 disks were printed for this experiment.

The image files were collected and compared in a similar manner to what is routinely done in the semiconductor industry. Because align marks are included on every disk, it is possible to align the image files and compare defectivity from disk to disk. As discussed above, particles dominate defectivity. Non-fill defects are typically an order of magnitude less than the particle related defects and tend to remain constant over the run. The results of the two imprint runs are shown in Figure 13. Plotted is the total defect area ratio as a function of imprint number. The target for total defect area ratio is $1\text{e-}4$, and the data comes in well under this target for both runs. It is clear that the improved cleaning process reduces defectivity and enhances template lifetime. Defectivity does trend upwards, however, and is clearly dependent on the number of particle related defects. Further improvements in disk cleaning are expected to mitigate the particle events and significantly extend the lifetime of the template.

4. Conclusions

Low defectivity during imprinting is a key issue to address for patterned media market. In this work, Candela systems have been used to inspect both wafers and disks. By improving the disk clean process, template lifetime has been improved by about a factor of two. Defect levels are promising, and it is clear that the reduction of initial template defects along with cleaner substrates will further reduce defectivity and extend template life. Future work will focus on additional improvements to the clean process and imprint runs designed to verify template lifetimes required for hard disk manufacturing.

5. Acknowledgments

The authors would like to thank Hoya for their excellent template fabrication work. The authors are also grateful for the inspection work performed by KLA-Tencor. Finally, the authors would like to express their gratitude to Intevac for interactions in developing a vapor phase adhesion layer process.

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Photomask 2010 Special Session Preview

From 'Plenty, but never enough' to 'Badly needed' – are we funding the right technology/wavelength?

For the Special Session in Monterey this year on Wed, Sept 15th, co-chairs **Brian Grenon** and **Wolf Staud** have solicited the contributions of industry luminaries on the various subjects and challenges that maskless lithography (ML2) is facing: starting with **Burn Lin** [Keynote], **Hans Pfeiffer** [historical background], **Neil Berglund** [CoO], **Aki Fujimura**, [design challenges], **David Lam**, [complementary lithography], **Ido Holzman** [inspection], **Tor Sandstrom** [platform], **Laurent Pain** [datapath], and many more tool and sub-system suppliers to give you a full day program on this more than viable alternative.

Please join us for what will surely be a very challenging and interesting session.

Session Overview:

The increasing cost of lithographic masks is raising concerns for future technology generations and the semiconductor roadmap. Cost-per-design is another limiting factor in diminishing the number of prototype starts. One could argue that EUV appears to benefit only true high-wafer-volume-per-mask end users that can absorb the cost through their wafer, chip, and systems cost.

As a result, semiconductor manufacturers are beginning to look for ways to reduce or eliminate the need for masks altogether – maskless lithography is one such approach.

In a sense, one variation of maskless lithography — electron-beam direct-write tools — have been around for decades and are still successfully used in the semiconductor industry for rapid device development. Typically, EBDW tools operate at 50keV electron-beam energy and have excellent resolution capabilities. The only reason the tools are not widely used in production is their lack of throughput. Multibeam maskless lithography offers all the benefits of EBDW while resolving the volume problem by implementing a massive parallelization of electron beams.

In contrast with EUV, massively parallel maskless lithography is an innovation on an *evolutionary* path that—to a large extent—capitalizes on existing e-beam technology parts (e.g., source, lenses, wafer stage, beam software, magnetic shielding, and tool software). The main advantage of ML2 is the realization of pattern transfer through an array of several hundreds or thousands of individually addressable electron beams, thereby pushing the potential productivity from hours-per-wafer into the wafer-per-hour regime. Furthermore, several ML2 tools can be clustered on the floor space allocated for just one EUV scanner, potentially providing 100 wph for the 22nm hp node, capitalizing on the advantage of using the same common infrastructure – with the added benefit of redundancy in case of downtime related to source, optics clean, defects, or general contamination problems.

Join the premier professional organization for mask makers and mask users!

About the BACUS Group

Founded in 1980 by a group of chrome blank users wanting a single voice to interact with suppliers, BACUS has grown to become the largest and most widely known forum for the exchange of technical information of interest to photomask and reticle makers. BACUS joined SPIE in January of 1991 to expand the exchange of information with mask makers around the world.

The group sponsors an informative monthly meeting and newsletter, BACUS News. The BACUS annual Photomask Technology Symposium covers photomask technology, photomask processes, lithography, materials and resists, phase shift masks, inspection and repair, metrology, and quality and manufacturing management.

Individual Membership Benefits include:

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- Eligibility to hold office on BACUS Steering Committee

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Corporate Membership Benefits include:

- One Voting Member in the SPIE General Membership
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2010



SPIE Photomask Technology

13-16 September
Monterey Marriott and
Monterey Conference Center
Monterey, California, USA
spie.org/pm

Late submissions will be considered by Chairs.



SPIE Lithography Asia - Korea

13-15 October
Hyatt Regency Incheon
Incheon, South Korea
<http://spie.org/la/>

2011



SPIE Advanced Lithography

27 February-4 March
San Jose Marriott and
San Jose Convention Center
San Jose, California, USA

Abstract submissions to open in May 2010.
spie.org/al

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